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BOARD # 269: MERGE: Multiphysics-Enriched Mixed Reality for Geotechnical Engineering Education

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MERGE: Multiphysics-Enriched Mixed Reality for Geotechnical Engineering Education

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ABSTRACT

Earth Trek is a mixed reality educational game that aims to enrich geotechnical engineering education through gamified learning. The game is designed for undergraduate geotechnical engineering students as part of the Multiphysics-Enriched Mixed reality for Geotechnical Engineering (MERGE) platform. It combines virtual reality technology with experimentation, field exploration, and engineering design through a series of mini-games based on standard lab assignments. These enable students to learn key concepts in geotechnical engineering in a virtual environment. Students can access various testing tools (e.g. thermal conductivity measurements and direct shear tests) through the game missions. They can also conduct parametric studies in the virtual laboratory to understand soil properties under different geological conditions. Students can also perform parametric studies in a virtual lab to understand the efficiency of heat transfer in geothermal piles. The game allows students to intuitively grasp complex theoretical concepts and practical operations through visualization and simulation tools. By completing the game's tasks, students can earn points and update the appearance of their characters, increasing their motivation to learn. Implemented across multiple institutions, Earth Trek not only improves students' laboratory skills and geotechnical knowledge, but also integrates smart city design concepts and develops their metacognitive and problem-solving skills. Beyond classroom teaching, the game supports self-paced learning, promoting lifelong education and preparing students for careers in geotechnical engineering.

INTRODUCTION

Today's society is facing global challenges due to climate change, energy shortages, and aging infrastructure. Geotechnical engineers play a crucial role in addressing these issues, but the complexity of geotechnical engineering demands interdisciplinary knowledge and innovation, posing challenges to current education models. Traditional education overemphasizes theory while neglecting interdisciplinary connections, limiting students' ability to solve complex multi-physical field problems. Students often find coursework disengaging and disconnected from practice, affecting their interest and career outlook.

Game-based learning (GBL) is gaining attention as an innovative approach in geotechnical education [1]. This approach transforms complex engineering concepts into intuitive, interactive, and fun learning processes through task-driven gamified experiences. Our educational platform, MERGE, provides a virtual environment for geothermal pile

design, covering site investigation, lab testing, numerical simulation, and structural design [2]. This approach aligns with the growing emphasis on advanced educational frameworks that integrate technology and interactive learning, such as the MetaEdu framework, which proposes a new paradigm for future education, focusing on a meta-level integration of technologies to enhance learning environments [3]. Through exploration and trial-and-error, students not only acquire multidisciplinary knowledge, but also improve their creative thinking and problem-solving skills.

Earth Trek is the first game in the MERGE platform. In the game, students simulate site investigations, conduct SPT, analyze soil properties, and study material behavior via experiments and simulations. Through several interactive modules, students can access simulations of standard lab assignments such as thermal conductivity testing and direct shear testing, enabling students to learn key geotechnical engineering concepts without the need for specialized lab equipment. Additionally, the gamified nature of Earth Trek and MERGE enables students to both cover geothermal pile design concepts, and to reinforce their problem-solving skills through an engaging gamified learning platform.

DEVELOPMENT OF MERGE PLATFORM

As the first game in the MERGE platform, Earth Trek is designed to cover geotechnical engineering lab concepts. To better engage students, the game takes inspiration from popular map-based mobile games such as Pokemon Go, using a virtual representation of students' real-world locations as the play environment. Students' main goal within the game is to design a geothermal pile. Geothermal piles are ground installations that help to heat and cool buildings more efficiently. In traditional geotechnical engineering education, undergraduate students only have a few opportunities to do lab tests and numerical simulations, so the details of geothermal pile design require reinforcement or teaching. Further, some students or institutions may not have access to measurement tools or labs to conduct these experiments, which Earth Trek addresses by offering an accessible lab experience with no equipment other than a smartphone or tablet.

Using the virtual map, students scope out a site for their geothermal pile and gather virtual soil samples. Once gathered, students can enter multiple laboratory settings with testing tools and equipment to conduct numerical testing on the virtual soil samples they collected. The virtual lab experiments are based on geotechnical engineering courses, namely the direct shear test and thermal conductivity test, two tests that help students learn about the properties of different types of soil, as well as the proper conditions for geothermal pile sites. Additionally, Earth Trek breaks up lab experiments with small mini-games that help to engage students while also imparting relevant facts and background knowledge. These mini-games enable students to collect virtual tools needed for further experimentation.

Once students have necessary tools, they can enter virtual lab environments to conduct two tests on the virtual soil samples they collected. Additionally, Earth Trek also features finite element simulation, helping students learn the test and design processes for geothermal piles without the need for specialized lab equipment. Through testing, students get soil parameters for their geothermal pile design, including thermal conductivity, cohesion, friction angle, and direct shear strength. More details on the full design of Earth Trek are mentioned in previous articles [3][4][5].

Experimental Simulation

As stated, Earth Trek offers gamified and virtual lab experiences focused on two soil-based experiments: A thermal conductivity test and direct shear tests. These lab experiments give students hands-on experiences without the need for specialized facilities or equipment. Students first gather a virtual soil sample and then conduct their experiments.

1. Thermal Conductivity: The thermal conductivity test measures a soil sample's thermal conductivity under steady-state conditions. In geothermal pile design, this is a key parameter as it determines pile efficiency. To run the experiment, students test different meter positions and determine how proper measurements are conducted, as well as recording the conductivity values for their own soil samples.
2. Direct Shear: The direct shear test allows students to explore the mechanical properties of their soil samples through simulated shear equipment. By varying the stress, shear forces, and pressure on their sample, as well as by adding water, students can gather stress-displacement data and analyze the shear strength, cohesion, and internal friction angles of their soil samples.

Beyond simulated experiments, MERGE also emphasizes data visualization. With only their smartphone, students can read virtual results, compare the properties of different soil samples, and record experimental results in real-time. In the direct shear test, students can also generate stress-displacement curves, all aiding in their understanding of proper geothermal pile design and soil properties.

Bearing Capacity and Knowledge Mapping Modules

Another module within MERGE is the Bearing Capacity Calculator (Fig. 1a). Using their experimental data, students can use the calculator to calculate real-time estimates of geothermal pile bearing capacity, including parameters such as end resistance (Q_p), lateral friction resistance (Q_s), and total bearing capacity (Q_u). With these values, students can determine which of their virtual soil samples has the best properties for the installation of a geothermal pile. Through the entire process, students also observe how the input parameters from their experiments affect their final results.

To further enhance learning, the Knowledge Mapping Module (Fig. 1b) scaffolds complex geotechnical concepts into a structured visual format. It presents key parameters, experimental data correlations, and environmental influences on geothermal pile design. The module highlights key parameters in geothermal pile design such as thermal conductivity, fluid velocity, and pile material properties. The module also helps students connect their data with real-world applications and environmental effects.

By integrating bearing capacity calculations with knowledge mapping, students can reference theoretical concepts while conducting real-time simulations. This approach strengthens their understanding of the complex, interdisciplinary nature of geotechnical engineering, bridging theory with practice through interactive learning.

SURVEY RESULTS

In Spring 2024, we conducted an instructional game test using the MERGE platform in three geotechnical engineering courses with 35 students. To assess the platform's effectiveness more comprehensively, we expanded our prior knowledge test from 11 to 18 questions on two topics, thermal conductivity and direct shear testing. Students completed pre- and post-tests before and after playing the game, respectively. The results showed overall score improvements, particularly in the "Direct Shear" section (10 questions), where the average increased from 2.34 to 7.06, indicating a significant learning impact. The "Thermal Conductivity" section (8 questions) also improved, with scores rising from 2.97 to 5.94, suggesting better understanding and retention. Fig. 2 visually presents these results, with the x-axis representing question numbers, the y-axis representing correct responses, and strongly orange and blue bars indicating pre- and post-test scores.

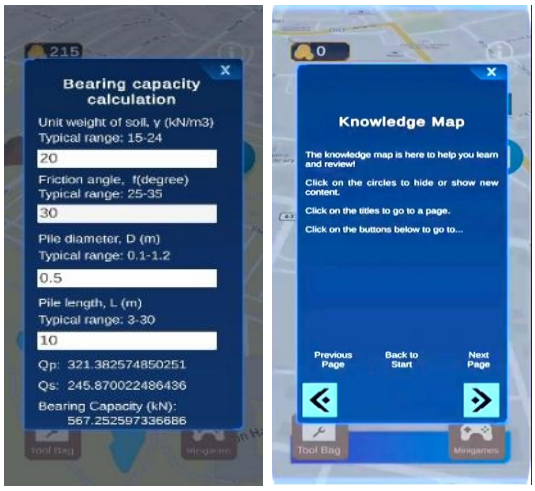

Fig 1. (a) Bearing capacity calculator (b) Knowledge map

However, there are some limitations with the current knowledge test. First, 35 students is still a small sample size, and while the results are promising, expanded testing is needed to ensure that our measured improvements are generalizable to a broader population. Likewise, as all testing was conducted at Rowan University, in the north-east United States, results might vary in differing student populations. For both points, broader testing is needed to further confirm our results. For future studies, we also plan to redesign our testing questions again to ensure that they are evenly challenging and relevant to the game scenarios. Additionally, we plan to expand MERGE with additional practical scenarios to help students to better learn and apply geotechnical engineering knowledge.

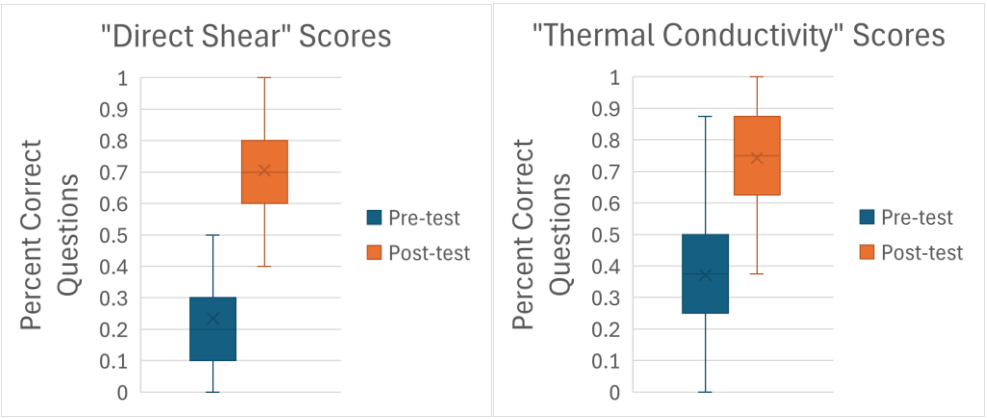

Fig 2. Statistics of correct answers before and after the game.

CONCLUSIONS AND FUTURE WORK

The development of the Earth Trek within the MERGE platform has been successfully completed and its educational value and practical effects have been verified through several rounds of laboratory testing and initial classroom trials. The platform integrates gamification, numerical simulations, and engineering design tasks, providing students with an innovative and interactive learning tool that effectively enhances their interest and engagement in geotechnical engineering.

Future work will focus on additional testing at more universities to cover a broader region and student demographic. Additionally, optimizing and improving aspects of the game is ongoing, as are efforts to promote the game and reach a wider audience. Through these efforts, we expect the MERGE platform to become an important tool in geotechnical engineering education and play an active role in cultivating a new generation of professionals.

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